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31. *The Ebino Earthquake Swarm and the Seismic Activity in the Kirisima Volcanoes, in 1968-1969, Part 1. Hypocentral Distribution of the 1968 Ebino Earthquakes inside the Kakuto Caldera.*

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1. Introduction

The 1968-1969 Ebino earthquake swarm was indeed a remarkable event in the southern part of Kyusyu Island. Since the beginning of February in 1968, earthquakes had frequently been felt in the Kakuto caldera located at the north-west of the Kirisima volcano group between Miyazaki prefecture and Kagosima prefecture, and they had still been active even at the end of the same year. These earthquakes are called "Ebino earthquakes" or "Ebino earthquake swarm". Because of such earthquakes, Ebino Town, Yosimatu Town etc. situated in the interior of caldera were seriously damaged. It came to be one of the serious problems among the residents as to when these earthquakes would end.

During the occurrence of the Ebino earthquakes, another one, the magnitude of which was 7.5, was recorded at 9:42 a.m. April 1, whose epicenter was in Hyuganada, off the south coast of Sikoku Island, southern Japan, more exactly speaking, between Miyazaki prefecture and Kooti prefecture. As the hypocenter was in the central part of the Hyuganada lying far off the land, the damage was not so much as anticipated for its magnitude. Some injured persons and some totally and partially destroyed houses, however, were reported, and the Tsunami waves caused by these earthquakes brought about some damage to the coasts of Miyazaki and Kooti prefectures. It is also questioned whether the Hyuganada earthquake has any causal relation with the Ebino earthquakes or not. These problems not only have been investigated in the fields of seismology, valcano physics, etc., but will be one of the most important subjects for the study on the prediction of earthquake. It seems to be not so easy to give a perfect answer to these problems. The historical approach to the earthquakes which occurred at those places is the only means to solve this kind of problems.

The Kirisima Volcano is a volcano group consisting of many cones which gather in the area stretching from the south-east to the north-west. From the south-east to the north-west there stand the cones with summit craters, such as Takatiho-mine, Naka-dake, Simmoe-dake, Oonami-ike, Karakuni-dake, Siratori-yama, Kurino-dake, and Iimori-yama, and then Kakuto caldera.

The boundary of Miyazaki prefecture and Kagosima prefecture runs through the central part of these volcanoes. The shape of the north-western wall of the Kakuto caldera is geographically ascertainable but that of the south-east part is not. A caldera is a kind of hollow in the shape of a pan in the volcano area, and, in this report, it has no special geological meaning. Generally the interior configuration of the caldera is fairly flat. In the interior of the Kakuto caldera, there exist Ebino Town, Yosimatu Town etc. and the railroad runs through those towns. The rest of the caldera is cultivated. It is this Ebino Town into which Masaki Town, Kakuto Town and Iino Town were amalgamated in 1966.

Although an outline of the historical seismic and eruptive activities of the Kirisima volcano group was treated in the previous paper, the problem should be discussed from another viewpoint.

2. Seismometrical observation of the Kirisima volcano group in 1966-1967

The Kirisima volcano group consists of active cones, such as, Takatiho-mine and Simmoe-dake, a lot of extinct cones, and the Kakuto caldera, whose localities are shown in Fig. 2. According to the seismometrical observation at the Kirisima Volcano Observatory, earthquakes originating from the Kirisima volcano group are classified into the following three types based on the localities of their epicenters.

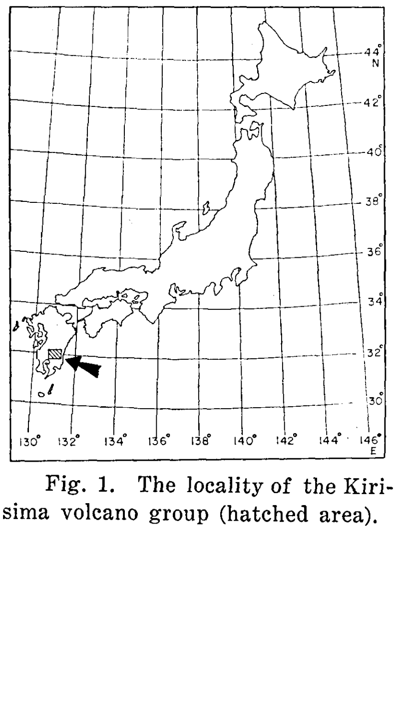

Fig. 1. The locality of the Kirisima volcano group (hatched area).

1) Earthquakes in swarms inside the Kakuto caldera
2) Extremely shallow earthquakes and volcanic tremors in the active cones, Takatiho-mine and Simmoe-dake
3) Shallow earthquakes in the ex-

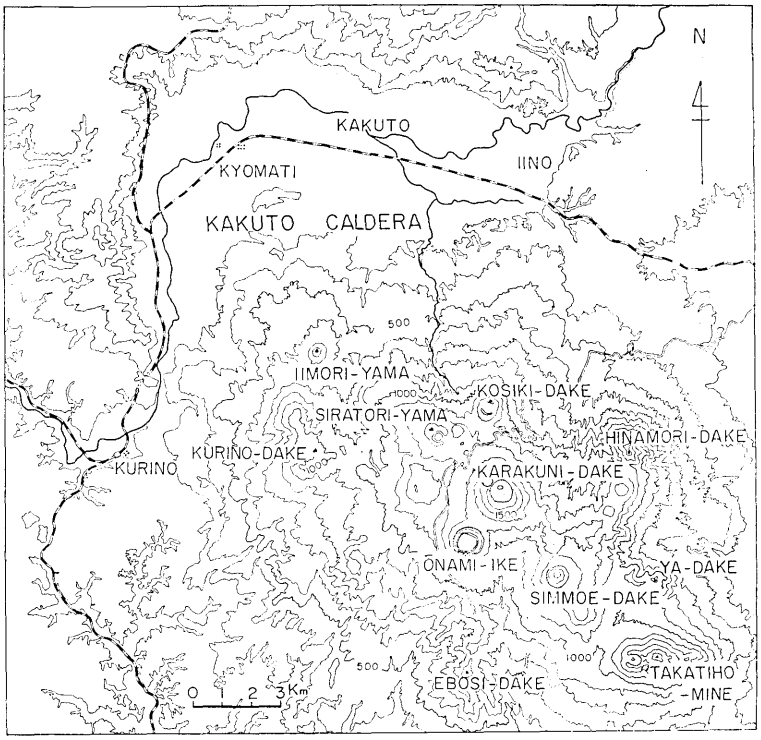

Fig. 2. Topographical map of the Kirisima volcanoes and the locality of the cones.

tinct cones.

Besides these earthquakes originating from the Kirisima volcano group, the seismograph at the observatory often records the earthquakes originating from Hyuganada, lying 300 km *E*. off the Kirisima volcano group.

In order to clarify the seismic activity of the above-mentioned areas, the seismicity of the Kakuto caldera, Takatiho-mine and Simmoe-dake is shown in Table 3 in a form of monthly frequency. As is seen in Table 3, the daily seismic frequency of the Kirisima volcanoes was 1.6 in 1966 and 1.4 in 1967 on the average, but small scale earthquake swarms took place in April, 1966 and in November, 1967, and lasted for a few days. The inhabitants of the villages in the caldera scarcely felt these earthquakes even near the epicenters. Although our seismometrical observation was not continued for a long period, the seismicity shows the normal state of seismic activity in the Kakuto caldera. Therefore, it may be natural that the seismicity of Kakuto caldera should be exceedingly high as compared with the Aira caldera located near Sakura-zima and the Oosima caldera. It must be added here that the seismic frequency of the Kakuto caldera was obtained by the standard seismograph at the Kirisima Volcano Observatory which was adjusted to 15,000 in magnification.

As reported in the previous paper, active volcanic cones frequently erupted up to the present. Since it is the main purpose of the Observatory to get continuous information with respect to the eruptive and seismic aspect, one transducer has been set near the margin of the Simmoe crater not so far from Takatiho-mine, and seismic observation was continued with the same sensitivity as it had been before.

Judging from the observation during the period from 1964 to 1967 and the state of the craters, the seismic frequency indicates the usual or normal state of the active volcanic cones, Takatiho-mine and Simmoe-dake.

Besides the earthquakes at these two places, shallow earthquakes took place in a lot of extinct cones lying between the Kakuto caldera and the two cones mentioned above. The hypocentral depth of these earthquakes is in a range from 1 km to 3 km which is the average depth of those of the other two places.

The seismic activity of the Kirisima volcano group during the period from 1964 to 1967 was in a normal or calm state.

During that period, our seismometrical net often recorded a series of earthquakes originating from Hyuganada. In Fig. 4, the seismic activity at the above three places of the Kirisima volcanoes is shown in a form of the daily frequency in the period from February, 1968 to July, 1968. It must be added that hypocentral positions of the 1966-1967 earthquakes were not so much different from those of the 1968 Ebino earthquakes which are illustrated in Figs. 6~9.

3. The seismometrical net covering the Kirisima volcano group

In order to report the remarkable seismic activity of the Kirisima volcano group in 1968 and 1969, it may be convenient to describe here the seismometrical nets covering the Kirisima volcano group.

The Kirisima Volcano Observatory (E. R. I.) has four networks; one ordinary network of the Ishimoto's acceleration seismograph and those of tele-recording system with transmission wire which have the following recorder stations corresponding to the respective networks.

Each net consists of a series of transducers which are set at various places in the Kirisima volcano group. The places where transducers are set and the characters of instruments are shown in Tables 1 and 2 and the map of Fig. 3.

Seismometrical net	Recorder station	Place covered
First net	Kirisima Volcano Observatory	Middle part of Kirisima vol. group
Second net	Okamoto Branch Observatory	Northern part of Kirisima vol. group including Kakuto caldera
Third net	Yunono Branch Observatory	Southern part of Kirisima vol. group including Takatiho and Simmoe

Table 1. Geographical position of the stations equipped with the transducers or the acceleration seismographs.

Stn.	Place	Latitude N	Longitude E	Altitude
1	Kirisima V. O. (1)	31°56′41.1″	130°50′32.3″	1215 m
2	Kamimonzen	〃 59 34.5	〃 50 11.1	430
3	Oonami-ike W	〃 55 17.9	〃 50 33.0	1180
4	Kurino-dake	〃 57 49.9	〃 47 51.5	1090
5	Simmoe crater W	〃 54 36.8	〃 52 36.4	1180
6	Karakuni-dake NE	〃 56 57.6	〃 52 16.0	1100
7	Suwa-zinzya	32 01 57.9	〃 48 44.6	303
8	Okamoto P. S.	〃 01 11.2	〃 47 11.3	305
9	Okamoto-ura	〃 01 05.8	〃 47 15.5	280
10	Kawazoe	31 59 50.4	〃 46 10.6	411
11	Miyosi	32 01 31.0	〃 47 34.0	289
12	Momogasako	32 01 08.0	〃 46 34.2	283
13	Deguti	〃 00 35.6	〃 47 13.8	290
14	Makiba	〃 00 01.5	〃 47 29.0	490
15	Mizunomi	〃 00 48.9	〃 48 05.6	299
16	Yunono	31 53 05.3	〃 51 59.9	785
17	Yunono-ura	〃 52 56.0	〃 52 02.3	790
18	Ebosi-dake	〃 53 22.3	〃 51 31.1	940
19	Simmoe-Naka-dake	〃 53 33.6	〃 52 34.7	1026
20	Simmoe crater S.	〃 54 03.3	〃 52 58.5	1215
21	Oonami-ike S.	〃 53 57.1	〃 52 01.0	915
22	Takatiho	〃 53 01.9	〃 53 56.3	980
23	Kirisima V. O. (2)	〃 56 38.4	〃 50 29.7	1200
24	Iino P. S.	32 02 36.4	〃 52 09.5	253
25	Utitate	〃 03 00.6	〃 45 55.3	217
26	Kurino-mati	31 56 54.6	〃 43 24.6	188

The Ishimoto's acceleration seismographs were set as the fourth net at four places around the Kakuto caldera in order to obtain the locality of hypocenters for the 1968–1969 earthquake swarm as soon as possible.

Table 2(a). The first seismometrical net.

Stn. No.	Place of transducer	Component	Magnification on smoked paper	Magnification on oscillo-graph paper
1	Kirisima V. O. (1)	2 horizontal	15,000	100,000-200,000
〃	〃	1 vertical	〃	〃
2	Kamimonzen	1 horizontal	〃	〃
3	Oonami-ike W.	1 vertical	〃	〃
4	Kurino-dake	1 horizontal	〃	〃
5	Simmoe crater N	1 vertical	〃	〃
6	Karakuni-dake NE	1 vertical	〃	〃

Table 2(b). The second seismometrical net.

Stn. No.	Place of transducer	Component	Magnification on smoked paper	Magnification on oscillo-graph paper
7	Suwa-zinzya	1 horizontal	15,000	100,000-200,000
8	Okamoto P. S.	1 horizontal	—	〃
〃	〃	1 vertical	—	〃
9	Okamoto-ura	1 horizontal	15,000	—
10	Kawazoe	1 horizontal	〃	100,000-200,000
11	Miyosi	1 vertical	—	〃
12	Momogasako	〃	—	〃
13	Deguti	〃	—	〃
14	Makiba	〃	—	〃
15	Mizunomi	〃	—	〃

Table 2(c). The third seismometrical net.

Stn. No.	Place	Component	Magnification on smoked paper	Magnification on oscillo-graph paper
16	Yunono	1 vertical	15,000	100,000-200,000
〃	〃	2 horizontal	〃	〃
17	Yunono-ura	1 vertical	—	〃
18	Ebosi-dake	1 〃	—	〃
19	Simmoe-Naka-dake	1 〃	—	〃
20	Simmoe crater S.	1 〃	—	〃
21	Oonami-ike S.	1 〃	—	〃
22	Takatiho	1 〃	—	〃

Table 2(d). The fourth seismometrical net.

Stn. No.	Place	Component	Sensitivity
23	Kirisima V. O. (2)	1 vertical	2 gal/mm
〃	〃	2 horizontal	〃
24	Iino P. S.	1 horizontal	〃
25	Utitate	1 vertical	〃
〃	〃	1 horizontal	〃
26	Kurino-mati	1 vertical	〃
〃	〃	1 horizontal	〃

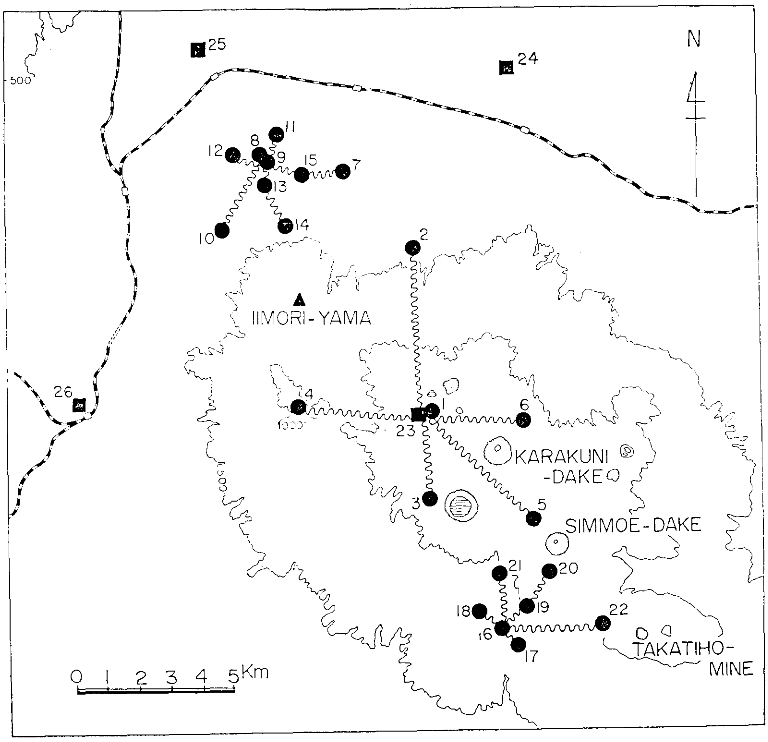

Fig. 3. The locality of the seismograph nets at the Kirisima volcanoes as of March-July, 1968.

4. The 1968-1969 Ebino earthquake swarm inside the Kakuto caldera

Historical events of seismic and volcanic activities of the Kirisima volcano group made one of the writers realise that it was most important to set a new seismometrical net covering the northern part of the Kirisima volcano group for the study of its internal structure and for the prediction of volcanic eruption of Simmoe-dake and Takatiho-mine. Consequently a seismometrical net was newly set as the second one in January, 1967, at Okamoto village, the central part of the Kakuto caldera.

A series of earthquakes had been caught by the first and second seismometrical nets from the beginning of February, 1968, several of which were felt by the villagers living in the caldera and sometimes even the rumble was heard by them. This seismic activity lasted for three weeks, and then the catastrophic earthquakes took place at 8 h 51 m (M=5.6) and 10 h 45 m (M=6.1), on February 21. The later one caused serious damage to dwelling houses, railroads and other constructions. It was also remarkable that landslides occurred at many places in and around the caldera on account of strong earthquake motions. At 0 h 59 m on March 25, the same area was visited by another strong earthquake (M=5.6) and there was immeasurable damage to the houses. In the earlier earthquakes the wooden houses had been partially damaged.

Total damage to the dwelling houses by the 1968 Ebino earthquakes is as follows;

The dead	3
The wounded	44
Totally demolished houses	498
Partially demolished houses	4677

Table 3. The monthly seismic frequency of the earthquakes originating in the Kirisima volcano group during 1966-1968.

Month	1966	1967	1968	1968 (by accel. seismogr.)
Jan.	20	33	26	0
Feb.	19	18	11393	398
Mar.	25	62	14352	745
Apr.	318	28	8269	363
May	39	32	4482	180
Jun.	26	28	1194	47
Jul.	31	26	1773	91
Aug.	11	14	553	19
Sept.	16	31	375	11
Oct.	22	21	519	14
Nov.	26	148	203	2
Dec.	28	70	168	2
Total	581	511	43307	1872

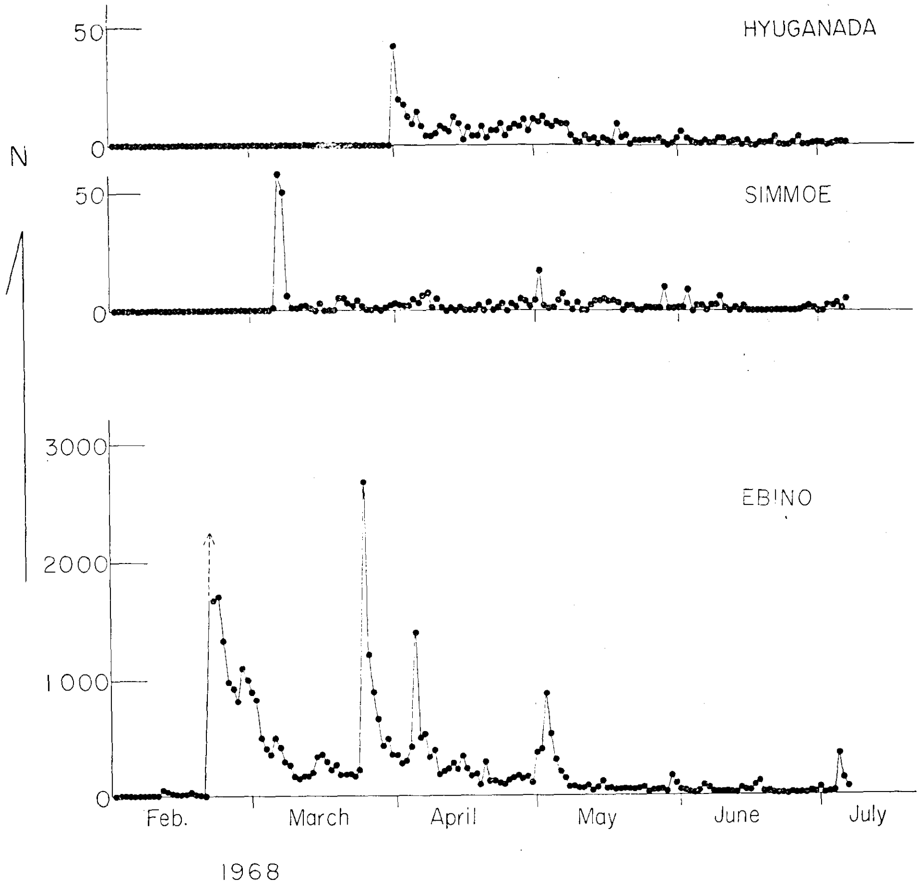

Fig. 4. The daily frequencies of the Ebino, Simmoe and Hyuganada earthquakes observed in the seismograph at the Kirisima Volcano Observatory

It was indeed unfortunate that a few persons were killed, but, luckily, no fire did break out.

The present Ebino earthquake swarm lasted for more than one year and at the present, the end of April, 1969, the seismic state of the Kakuto caldera still keeps a level higher than the normal seismic one.

In Fig. 4, the daily frequencies of the Ebino earthquake swarm are shown, observed by the high sensitive seismograph set at station No. 1 in K. V. O. at 10～13 km distant from the central part of their epicenters. Also the daily frequencies of earthquakes originating from the active cones, Simmoe-dake and Takatiho-mine, and Hyuganada are shown separately in Fig. 4, which were recorded by the above seismograph set at stations No. 1 and No. 5.

Reviewing the development of the 1968-1969 Ebino earthquake swarm, the most conspicuous characteristic is that it repeated distinctly ebbs and flows several times, as it had been expected from the past seismic activities at the Kakuto caldera.

As soon as the present Ebino earthquake swarm started, the writers newly set the third seismometrical net covering Takatiho-mine and Simmoe-dake, and observation commenced on March 15, 1968. Before the third net was set, the earthquakes originating from Takatiho-mine and Simmoe-dake were caught to some extent at the southern part of the first net, but it was not sufficient to ascertain the very locality of their hypocenter.

On March 7 and thereafter, however, a series of extremely shallow earthquakes and volcanic tremor of continuous train lasting for several minutes began to appear on the seismogram. It must be noted that the seismic activity, which started from the northern end of the Kirisima volcano group at the beginning of February, shifted to the south through a series of extinct volcanoes, the middle of the volcano group; it moved to the active cones, Simmoe-dake, after March 7, and Takatiho-mine, after March 22, which is located at the southern end of the volcano group.

The 1968 seismic activities at the Kakuto caldera, Simmoe and Hyuganada, which are illustrated in Fig. 4 in their daily seismic frequencies, took place almost at the same time as the 1913 and the 1961 seismic and volcanic activities of the same three places. The writers have a special interest in the above phenomena of whether they occurred in an accidental coincidence or not. The problem will be studied in a forthcoming paper.

5. The geographical distribution of hypocenter of the Ebino earthquake swarm and the Simmoe and Takatiho earthquake swarms

(a) The Ebino earthquake swarm

For the convenience of description, the writers define the 1968-1969 Ebino earthquake swarm as follows; the earthquakes which took place inside the Kakuto caldera during the period from February 1, 1968, until monthly seismic frequency of the Kakuto caldera came down to the normal level. Determination of the hypocentral distribution and shifts of hypocentral location will give the fundamental answer to solve the present phenomena of the Kirisima volcano group. Therefore, we made various experimental observations before and during the Ebino earthquake swarm. The locality of the earthquake swarm is found out by the most simple method using the fourth seismometrical net which consists of Ishimoto's acceleration seismograph set at four stations around the epicentral area.

Though a series of earthquakes which occurred in the earlier stage of the swarm, before February 21, were of minor scale in their intensity, the localities of their hypocenters were found out by the stations Nos. 1, 2, 4, 8 and 9 of the first and the second nets which consist of higher sensitive seismographs. The series of Ishimoto's acceleration seismograph caught the hypocenters of earthquakes which occurred after the strong one on February 21 and were felt, at least, in the Kakuto caldera.

The localization of these earthquakes was determined on the basis of S–P observed at the four places. As to the shift of the locality of shocks due to development of the phenomena, the geographical distribution of hypocenters at four different periods is illustrated in Figs. 6～9.

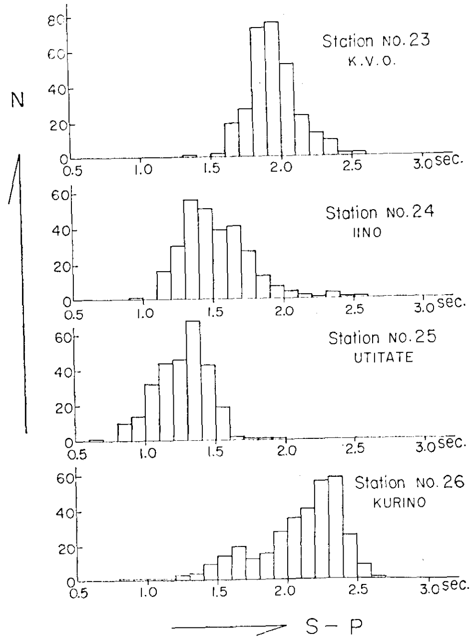

Fig. 5. Frequency distribution of S–P of the 1968 Ebino earthquakes observed by Ishimoto's acceleration seismograph.

The hypocentral depths of these earthquakes are distributed in a range from 3 km to 9 km as are seen in the same figures. It is, however, usual that the hypocentral depth of the shocks of the so-called A type earthquake at volcanic regions is in the range of hypocentral depth mentioned above.

Although we do not find any special change with respect to the hypocentral depth during that period, the epicentral position of shocks shifted twice or three times systematically, especially after big shocks. As is seen to some extent in Figs. 6～9 it is clear that the center of the epicentral area was in 1～2 km south of Kyomati near the boundary of Miyazaki and Kagosima prefectures and then moved 2～3 km toward east or south of Kakuto district immediately after the strong earthquake on March 25 which resulted in damage to the dwelling houses at Kakuto Town.

Since the earthquakes, discussed above on the basis of result of the fourth net, were also recorded more precisely by the other nets, the

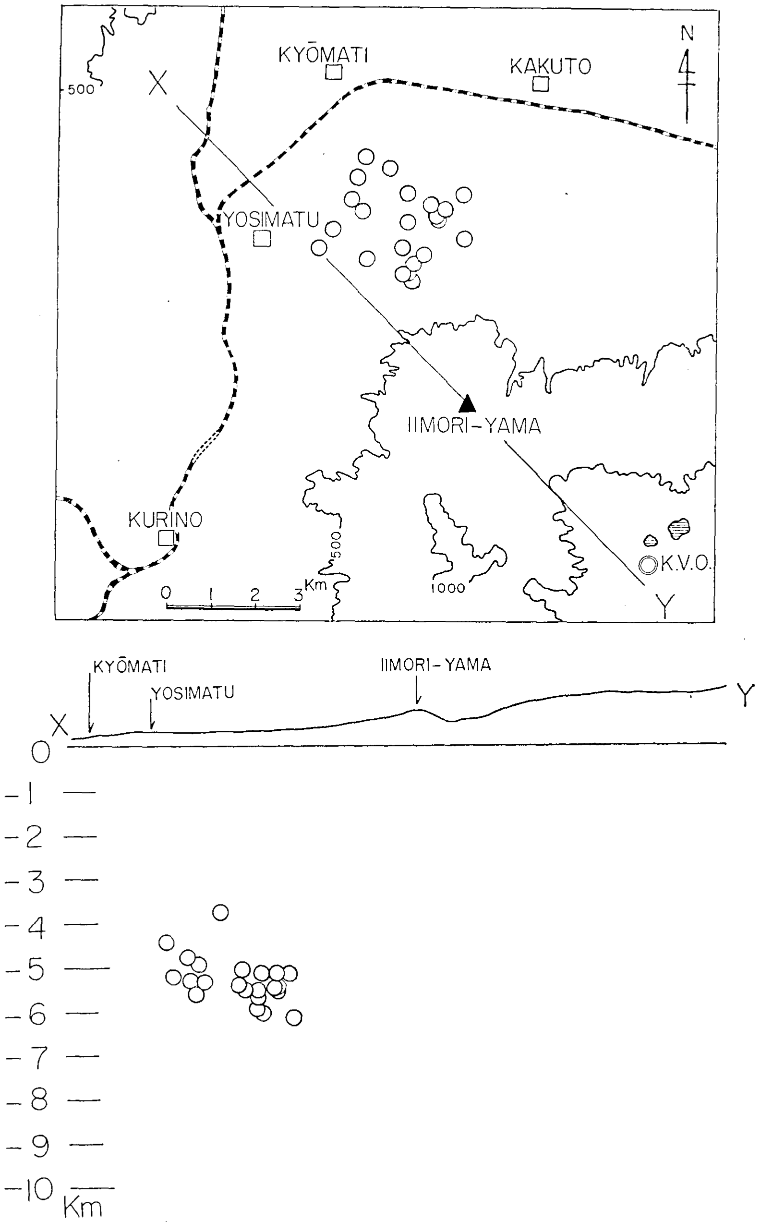

Fig. 6. Hypocentral distribution of the Ebino earthquake swarm before the catastrophic earthquake on February 21. (Feb. 11-21, 1968.)

problem concerning the hypocentral positions of the Ebino earthquake swarm can be studied in the arrival time of the initial phase recorded by the first, second, and third seismometrical nets. It is remarked that the center of the epicentral area of the 1968-1969 Ebino earthquakes

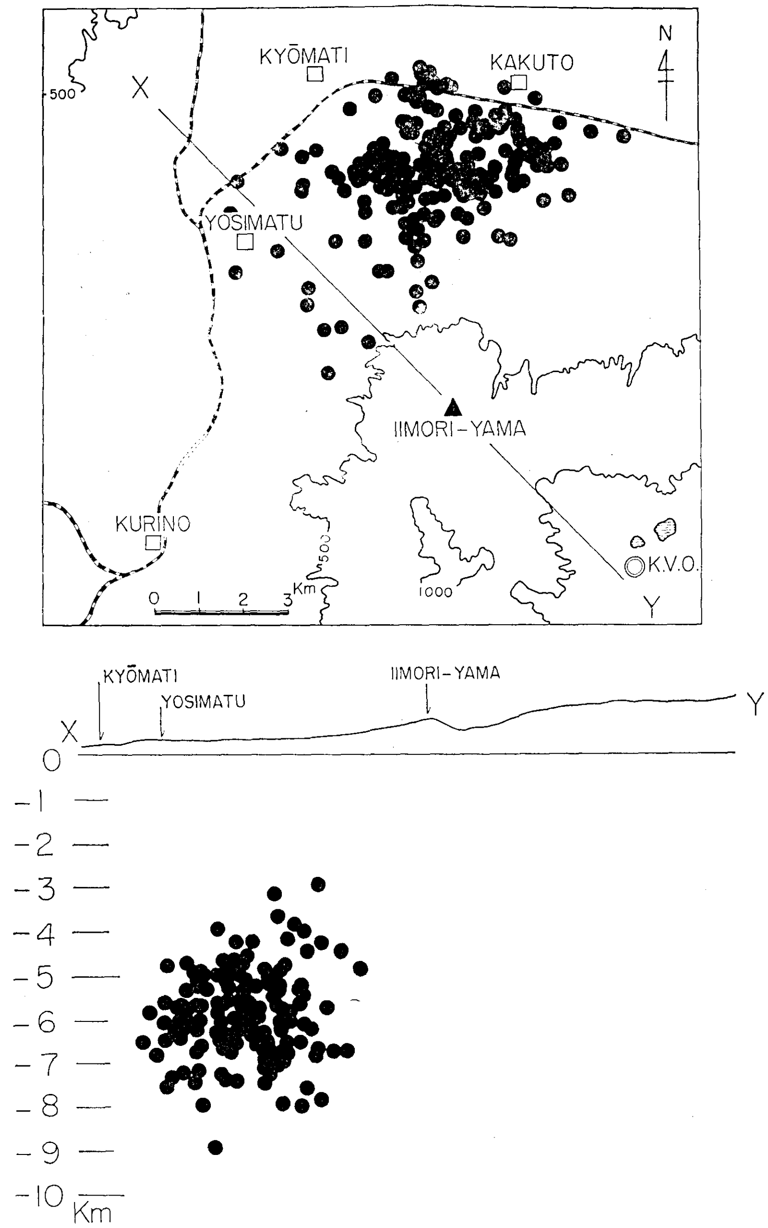

Fig. 7. Hypocentral distribution of the Ebino earthquake after the catastrophic earthquake on February 21. (Feb. 21-Mar. 31, 1968.)

is located 1 or 2 km north from that of the 1961 Iimoriyama earthquake swarm which was shown on the geographical distribution of hypocenter in the previous paper.

According to the result of observation by the first net, the frequency

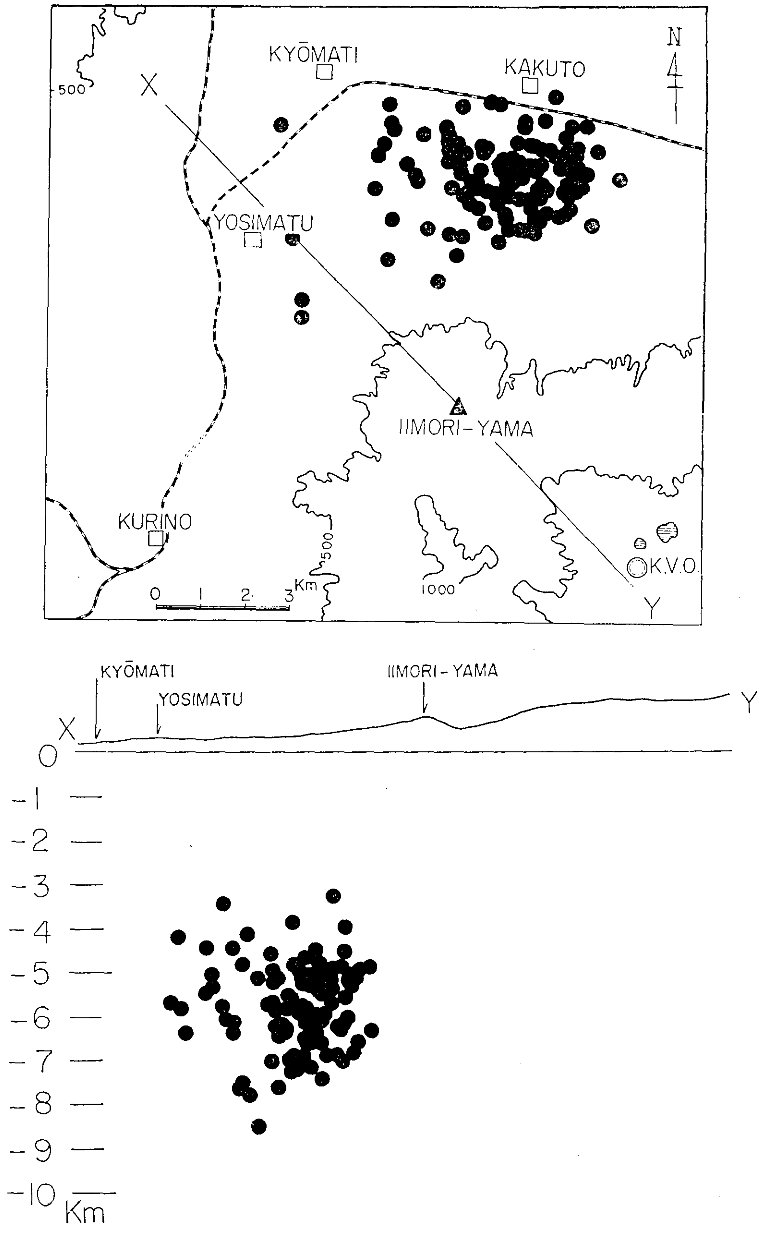

Fig. 8. Hypocentral distribution of the Ebino earthquake swarm during Apr. 1-May 31, 1968.

of the earthquakes originating from the extinct cones, Karakuni-dake, Oonami-ike, Kurino-dake and Siratori-yama, which are situated in the south-east of the Kakuto caldera, and from the dormant cones, Simmoe-dake and Takatiho-mine, increased more or less after the outbreak of

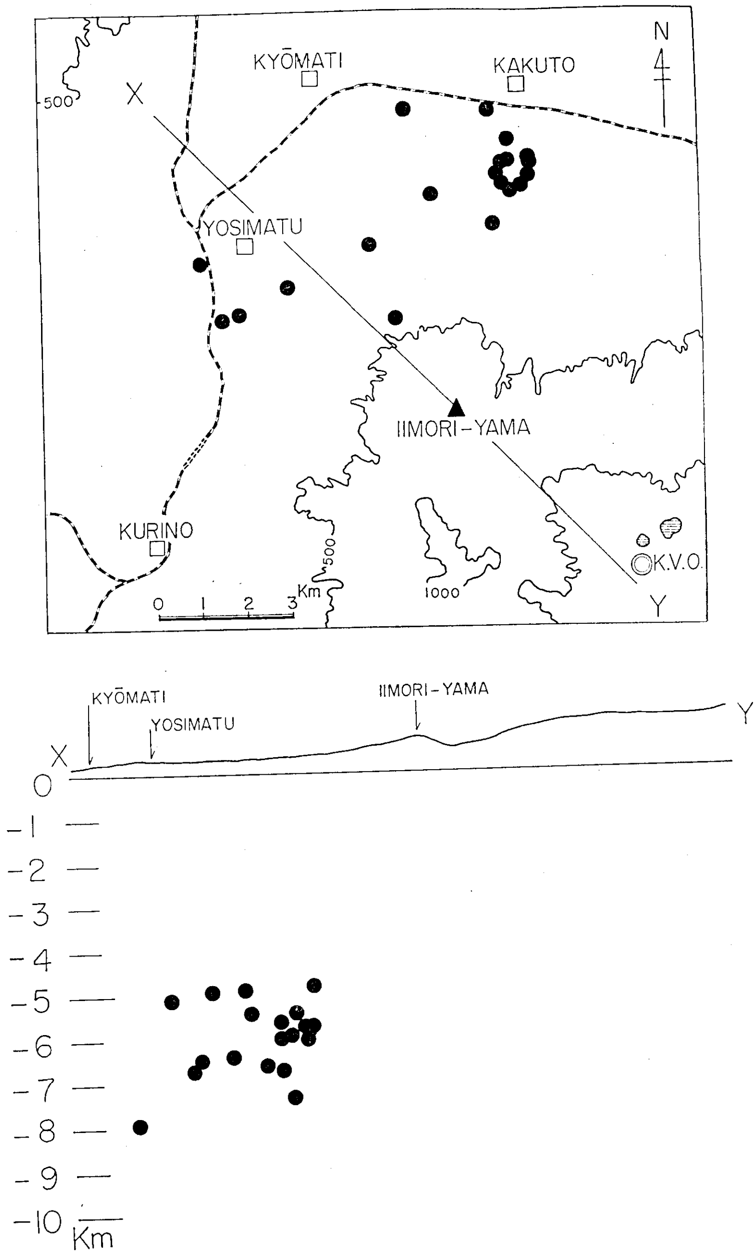

Fig. 9. Hypocentral distribution of the Ebino earthquake swarm during June 1-Aug. 31, 1968.

the Ebino earthquake swarm. These earthquakes are estimated at a range from 0 km to 3 km in their hypocentral depth and classified into the A and B types earthquakes.

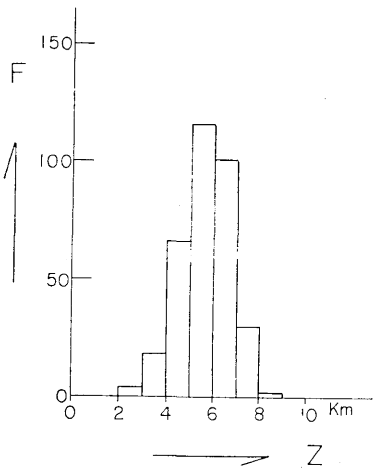

Fig. 10. Frequency distribution of the hypocentral depth.

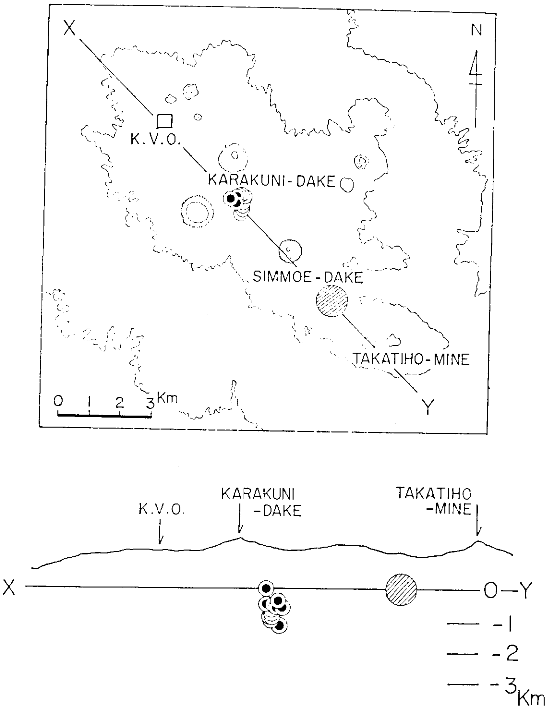

Fig. 11. The geographical position of *B*-type shock including A-type one near Simmoe and Takatio.

(b) The 1968 Simmoe earthquake swarm and volcanic tremor

As already described, a series of extremely shallow earthquakes in minor swarm took place on March 6–8, 1968, at the northern foot of Simmoe, of which the depth was estimated to be between the earth's surface and depth of 2 km based on S–P and displacement amplitude. The majority of these earthquakes will be classified into the B type shock. In Fig. 11, the geographical position of these shocks is illustrated with that of the Ebino earthquake swarm. On the other hand, volcanic tremor with continuous train appeared on the seismograms, which was obtained by the transducers set near Simmoe-dake. The

Table: Volcanic tremor obtained by Station No. 5

Date & time	Vibration period	Max. amplitude	Duration time
Mar. 7 15 h 17 m	0.20 sec	1.8 micron	2.2 minutes
Mar. 7 20 h 47 m	0.15 sec	0.3 micron	2.5 minutes
Mar. 8 00 h 26 m	0.08 sec	0.3 micron	5 minutes

time of its appearance, mean vibration period, maximum amplitude and time of continuation from Station No. 5 are listed in the previous page.

Judging from the amplitude distribution of the tremors which were obtained at a lot of stations, the origin of these tremors was estimated to be at the floor of the crater Simmoe which had erupted on February 17, 1959.

(c) The 1969 minor earthquake swarm of Takatiho-mine

We have been concerned with the problem of the shift of seismic activity in the Kirisima volcano group in the historical view of development of events, since the present Ebino earthquake swarm broke out. It is indeed worthy of note that the heavy earthquake swarm inside the Kakuto caldera situated at the northern end of the Kirisima volcano group was followed by frequent earthquakes originating from the series of extinct cones situated at the south-east of the caldera and by a minor activity of the B type earthquake and volcanic tremor in Simmoe-dake. When the seismic activity of Simmoe-dake came to an end, in March, 1968, and the remarkable seismic activity took place at Volcano Sakura-zima in May and June, 1968, we were much interested in whether the present seismic activity of the Kirisima volcano group ceased soon after the March 1968 activity of the Simmoe summit crater or extended or shifted to Takatiho-mine situated at the southernmost end of the Kirisima volcano group, which had been in an inactive state since the 1913 eruption.

However, a series of minor earthquake swarm of the B type began to occur at Takatiho-mine on March 22, 1969, and its activity did not cease yet at the end of March. It should be noted that the activity at Takatiho-mine indicated the final stage of the 1968–1969 marked seismic activity of the Kirisima volcano group, though it had possibly been expected from the 1913 seismic and eruptive activity of that district.

The following table is the list of the daily frequency of the Takatiho earthquake swarm.

Date	Daily freq.
March 22	33
23	30
24	25
25	12

By examining the seismograms of the first and third nets, the epicentral area of the earthquake swarm was estimated at $1.5 \sim 2$ km north-west of the summit of Takatiho and the hypocentral depth was less than 1 km. The geographical position of the above-mentioned earthquakes is shown in the map of Fig. 11. In the present stage of the Kirisima volcano group, it will be required to watch whether the seismic activity of Takatiho-mine will develop to its eruption or not.

6. Frequency and magnitude in the 1968-69 earthquake swarm

The writers will touch here on the relation between seismic frequency and its maximum amplitude of the present earthquake swarm and the coefficient of the Ishimoto-Iida experimental formula. The problems were dealt with by a series of seismograms observed with vertical component of Ishimoto's acceleration seismograph at the Kirisima Volcano Observatory. As the result, it is clarified that the above-mentioned relation is concerned with the seismic frequency and the maximum acceleration amplitude.

During the period from February 1, 1968, to February 28, 1969, the seismograph recorded 1,888 earthquakes belonging to the Ebino earthquake swarm, whose maximum acceleration is more than 0.2 gal or 0.1 mm of trace amplitude on seismogram. The result of calculation indicated the value of the coefficient m, 2.48 a little larger than that of usual or tectonic earthquakes. In order to examine if the value of the coefficient might change during that period, the earthquakes were divided into two groups; 669 earthquakes before March 24 and 1226 ones thereafter. The values of the coefficient are listed in the following table.

Period	Number of quake	Value of m
Feb. 3-Mar. 24, '68	669	2.56 ± 0.11
Mar. 25-Feb. 28, '69	1226	2.35 ± 0.01
Feb. 3, '68-Feb. 28, '69	1895	2.48 ± 0.03

As is clearly shown in the above table, the values of the coefficient of the two groups are identical with those of total earthquakes. It is interesting to compare these values with those of other earthquake swarms in the volcanic districts including 1965–1967 Matsushiro earthquake swarm. In the Matsushiro earthquake swarm, the same problem was studied by T. Iwata on the basis of seismometric observation by the same acceleration seismographs which were set about 1.0 km distant from the center of the epicentral region. According to their results, the value of the coefficient was in the range from 2.0 to 2.4 during the period of the Matsushiro earthquake swarm. On the other hand,

Table 4. The maximum vertical acceleration amplitude and the seismic frequency of the Ebino earthquakes observed at the Kirisima Volcano Observatory (Feb. 3, 1968–Feb. 25, 1969).

Maximum vertical acceleration	Number of quake	Maximum vertical acceleration	Number of quake
0.6- 0.7 gal	352	10.6-10.7 gal	1
0.8- 0.9	210	10.8-10.9	1
1.0- 1.1	173	11.0-11.1	2
1.2- 1.3	108	11.2-11.3	1
1.4- 1.5	93	11.4-11.5	0
1.6- 1.7	72	11.6-11.7	1
1.8- 1.9	47	11.8-11.9	0
2.0- 2.1	46	12.0-12.1	0
2.2- 2.3	32	12.2-12.3	1
2.4- 2.5	22	12.4-12.5	1
2.6- 2.7	22	12.6-12.7	0
2.8- 2.9	14	12.8-12.9	0
3.0- 3.1	15	13.0-13.1	1
3.2- 3.3	14	13.2-13.3	0
3.4- 3.5	7	13.4-13.5	0
3.6- 3.7	11	13.6-13.7	0
3.8- 3.9	12	13.8-13.9	0
4.0- 4.1	6	14.0-14.1	2
4.2- 4.3	6	14.2-14.3	0
4.4- 4.5	3	14.4-14.5	1
4.6- 4.7	5	14.6-14.7	0
4.8- 4.9	3	14.8-14.9	0
5.0- 5.1	5	15.0-15.1	0
5.2- 5.3	2	15.2-15.3	0
5.4- 5.5	5	15.4-15.5	0
5.6- 5.7	2	15.6-15.7	0
5.8- 5.9	2	15.8-15.9	2
6.0- 6.1	1	16.0-16.1	1
6.2- 6.3	3	16.2-16.3	0
6.4- 6.5	2	16.4-16.5	0
6.6- 6.7	0	16.6-16.7	0
6.8- 6.9	1	16.8-16.9	1
7.0- 7.1	1	17.0-17.1	0
7.2- 7.3	2	17.2-17.3	1
7.4- 7.5	0	17.4-17.5	0
7.6- 7.7	1	17.6-17.7	0
7.8- 7.9	1	17.8-17.9	0
8.0- 8.1	1	18.0-18.1	0
8.2- 8.3	3	18.2-18.3	1
8.4- 8.5	2	18.4-18.5	1
8.6- 8.7	1	18.6-18.7	1
8.8- 8.9	0	18.8-18.9	1
9.0- 9.1	1	19.0-19.1	0
9.2- 9.3	1	19.2-19.3	1
9.4- 9.5	0	19.4-19.5	0
9.6- 9.7	0	19.6-19.7	1
9.8- 9.9	1	19.8-19.9	0
10.0-10.1	2	20.0-20.1	0
10.2-10.3	2	20.1 <	9
10.4-10.5	0		
		Total	1347

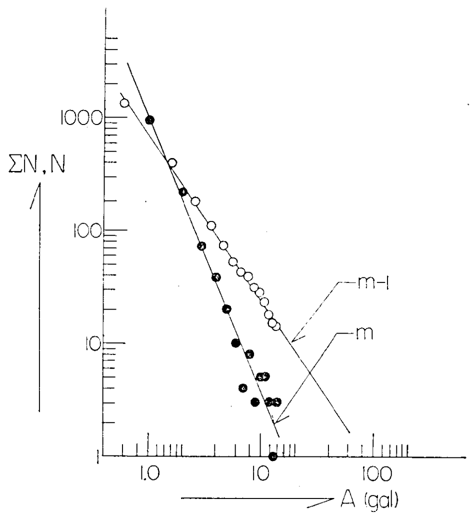

Fig. 12. The relations between the maximum acceleration and frequency of the 1968 Ebino earthquake swarm.

the writers investigated the same problem based on the seismic observation by the displacement seismographs set at Komoro, 35 km southeast of the epicentral area. The writers dealt with the seismograms of the Matsushiro earthquakes, of which the maximum amplitude on the seismogram is more than 1.0 mm or 3.0 micron in the actual displacement. Since the seismographs at Komoro recorded a great number of earthquakes originating from Matsushiro, the value of the coefficient is obtained by a series of earthquake groups which are separated according to period as is shown in Table 5. As the values of m are in a range between 2.04 and 2.17 as is seen in Table 5, it is reasonable to say that the value of the coefficient m for the Matsushiro earthquake swarm was almost constant throughout the period of development, and is not so much different from that of the usual earthquakes. Moreover, it must be added that the above-mentioned value is almost identical with that obtained by T. Iwata.

As was described above, the value of m in Ishimoto and Iida's formula was studied with respect to the Matsushiro and Ebino earthquakes in which the value of m was separately obtained in the several periods of their development of the seismic activity. As the result, it

Table 5. The Ishimoto-Iida's coefficients in various periods of the 1965-1967 Matsushiro earthquake swarm.

Period	Number of quake (N)	Value of coefficient (m)
Aug. 1-Nov. 30, 1965	4421	2.07
Dec. 1-Mar. 31, 1966	12852	2.07
Mar. 1-31	6132	2.17
Apr. 1-30	18171	2.11
May 1-31	14038	2.08
Jun. 1-30	8267	2.06
Jul. 1-31	6229	2.12
Aug. 1-31	21060	2.12
Sep. 1-30	9864	2.04
Jan. 1-Dec. 31, 1966	85612	2.06

was evident that it did not show any noticeable change through the period in the respective earthquake swarms.

It is necessary, however, to remark that the value of m for the 1968–69 Ebino earthquake swarm and for the earthquakes which took place in the same area during the period from 1964 to 1967, is slightly larger than that of the Matsushiro earthquake swarm, notwithstanding that the two earthquake swarms are almost the same in the depth distribution of their hypocenters.

As another example of the earthquake swarm in the volcanic region, the same problem may be introduced here with respect to the 1959 Hakone earthquake swarm. The Hakone earthquake swarm was observed not only by a net of displacement seismograph, but also by that of Ishimoto's acceleration seismograph, both of which were set inside the Hakone caldera. Based on these observations, the values of the coefficient m were 2.64 ± 0.02 for the acceleration amplitude and 2.60 ± 0.02 for the displacement one. These values are a little larger than that of the Ebino earthquake swarm. On the other hand, the hypocentral depth of the Hakone 1959–1960 earthquake swarm was in a range from 1 to 4 km and exceedingly shallower than those of the other two earthquake swarms. Judging from the general opinion based on Mogi's experiment of rock samples that the greater the heterogeneity of the material is, the larger the value of m is, it will be reasonable for the shallower earthquakes to indicate a larger value.

7. Conclusion

The remarkable earthquake swarms broke out at the beginning of February, 1968, and lasted for more than one year in the Kirisima volcano group, which consists of the Kakuto caldera, a series of extinct and dormant cones standing in a narrow belt from north-west to south-east.

The earthquakes were observed by the permanent and temporary seismometrical nets which covered the volcano group. In this report, the writers deal with the development of the seismic activity in a condensed form and the geographical distribution of hypocenters based on the observation by a net of the acceleration seismograph of low magnification. It was the most remarkable feature of the present event that the seismic activity which started in the Kakuto caldera shifted toward the south-east along the Kirisima volcanic belt, in other words, to the northern foot of Karakuni-dake, then Simmoe-dake and finally Takatiho-mine situated at the south-eastern end of the volcanic belt. It is indeed interesting that the pattern of shift of the present seismic activity is perfectly identical with that of the 1913 seismic and eruptive activity of the Kirisima volcano group.

The writers studied the relation between the magnitude and frequency of the 1968-1969 Ebino earthquake swarm and compared it with those of the 1965-1967 Matsushiro and the 1959-1960 Hakone earthquake swarms.

In concluding, the writers wish to express their sincere thanks to Mr. H. Kuroki, Governer of Miyazaki prefecture, and to the inhabitants of the epicentral area for their help and kindness in giving facilities during our observation and field investigation. General acknowledgements are due to Mr. T. Miyazaki and Mr. S. Hiraga who helped us by repeated observations.

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31. 1968-1969年のえびの地震群及び霧島火山群の地震活動（第1報）

えびの地震群の震源分布

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昭和 43 年2月初旬より，霧島火山群北部の加久藤カルデラ内部に，地鳴りを伴つた地震が発生しはじめたが，2 月 21 日 8時及び 10 時に，えびの町，京町南部では，局部的に震度 6 と推定される地震が発生し，えびの町，吉松町で多数の家屋が全壊し，山崩れ，道路の破損，水道管の破裂等多大の損害を生じた．

1) 上記地震発生地域は，過去においてしばしば地震群が発生し，家屋等に損害を受けた経験を持つている．例えば，大正2年（1913 年）の真幸地震群，1961 年の飯盛山地震群等であるが，これらの地震群の震央地域は，今回と同様に飯盛山の北部，えびの町，京町，加久藤地域の南部を含む加久藤カルデラの内部，深さ 3 km から 9 km に震源を持つ地震群である．

2) 過去の地震群が，カルデラ内部に発生し，その地震活動が，霧島火山群に沿つて南東に移動し，その南東端に位置する高千穂の噴火活動に発展した歴史に鑑み，霧島火山地域の地震並に火山活動の研究のためには，先ず加久藤カルデラ内部に，地震観測網を設置する必要を考え，1966 年に岡元地区の3カ所に，有線式遠隔記録法を用いて，岡元小学校に地震記録の観測点を臨時に設置した．従つて今回の地震群の発生と同時に，上記観測網と，霧島火山観測所のそれとによつて，充分に観測され，震源位置，地震活動の進展等について，必要な情報を得ることができた．

3) 2 月 21 日に強震が発生するに及んで，2 月下旬より 7 月下旬にかけて，地震観測網を拡大し，増強して，次のような観測網によつて，霧島火山群一帯の地震観測を実施した．

1. 第1観測網，霧島火山観測所を記録点とする 6 カ所 8 台の換振器による，15,000 倍の連続観測及び，オシログラフに分流して，100,000～200,000 倍の高倍率観測．
2. 第2観測網　岡元小学校(後に同校庭内に新設した霧島火山観測所岡元分室)を記録点とする 9 カ所 10 台の換振器による，5,000 倍の常時観測及び 100,000～200,000 倍のオシログラフによる定時観測.
3. 第3観測網　えびの地震群の発生は，やがて火山群の南東部の新燃岳，高千穂峰の活動に波及することと推定し，同地域の湯之野国民宿舎（後に同所に湯之野分室を仮設する）を記録点とする7カ所9台の換振器で第 1，第2の観測網と同様の方法を用いて観測した．
4. 第 4 観測網，石本式加速度計を霧島火山観測所外，栗野町，えびの町飯野及び内竪地区の 4 カ所に設置し，有感地震を主な対象とする観測網を設置した．

4) 今回の地震活動の発展の状況を知るために，火山観測所の加速度地震計および，15,000 倍の高倍率地震計による地震数を日頻度で示した．

5) 地震群の震央位置を，第1近似として，第4観測網による 4 カ所の S-P によつて，震源の位置を定めた．震央は 1961 年の飯盛山地震群のそれよりやや北方に集中して発生した．震源の深さは，3 km～9 km に亘つて分布するが，大部分は 4 km～6 km の深さであつた．

6) 火山観測所の加速度地震記録を用いて，最大振幅の頻度との関係を調べた結果，石本飯田の係数 m の値は 2.4 となつた．その値は，1959～1960 年の箱根火山のカルデラ内部に，発生した地震群のそれと，ほぼ同じであるが，1966 年～1968 年の松代地震，小諸の観測結果から求めた 2.0 より著しい大きな値である．松代地震群の震源の深さは，今回のそれと，ほぼ同じであるにもかかわらず，著しく相違する点が興味をひく．

第 2，3，4 観測網による，観測結果については，第 2 報以下で報告する．

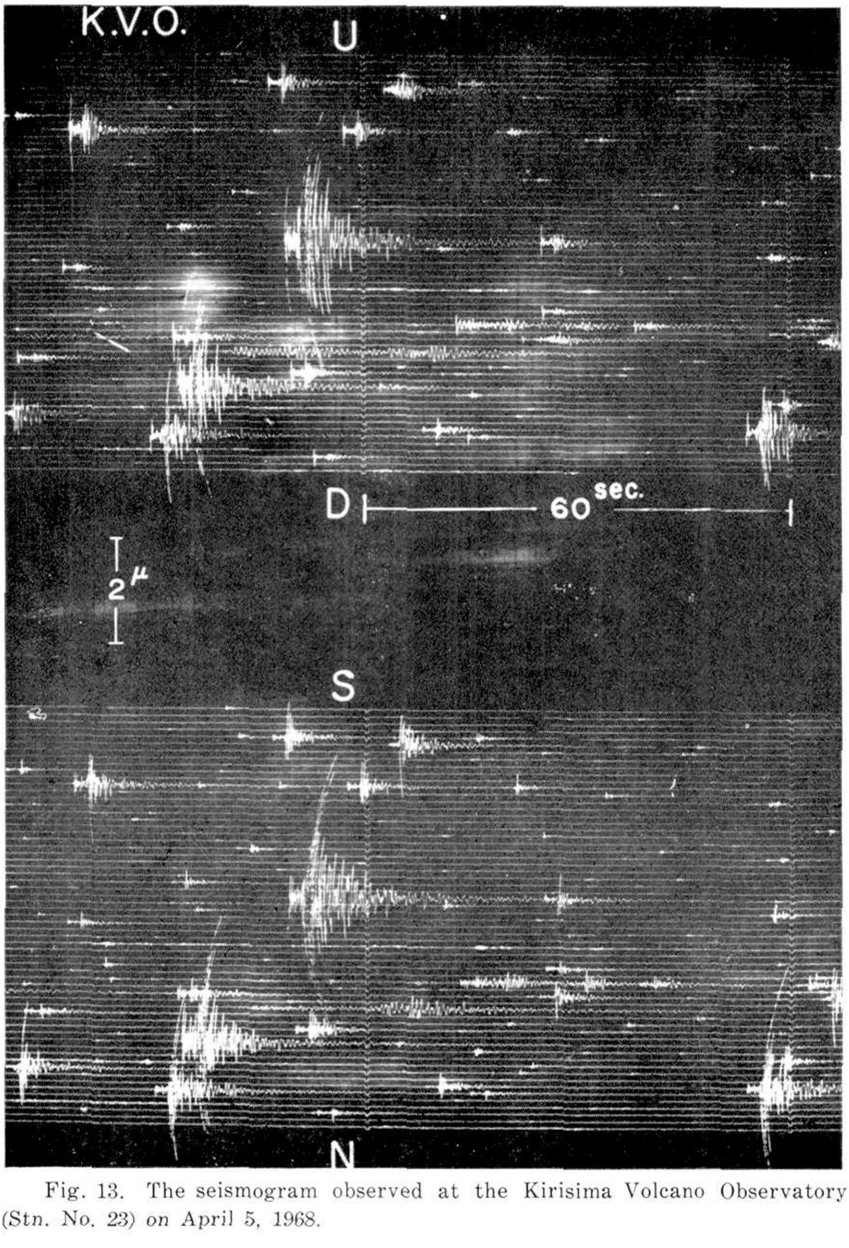

Fig. 13. The seismogram observed at the Kirisima Volcano Observatory (Stn. No. 23) on April 5, 1968.

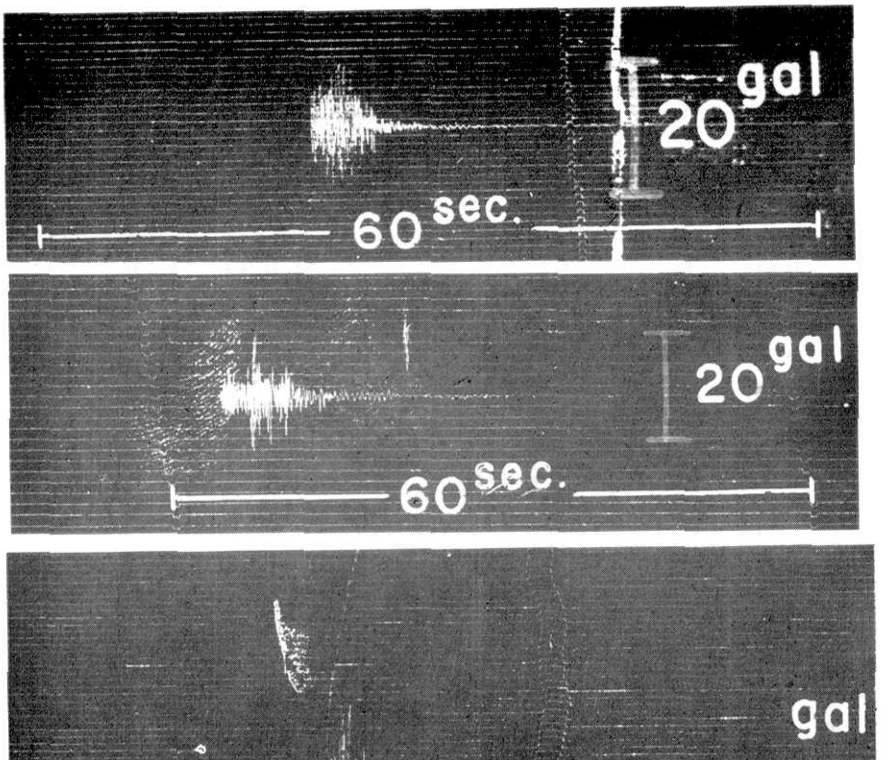

Fig. 14. The seismogram of the earthquake at 15h 51m 33s on March 28, 1968, observed at four stations.

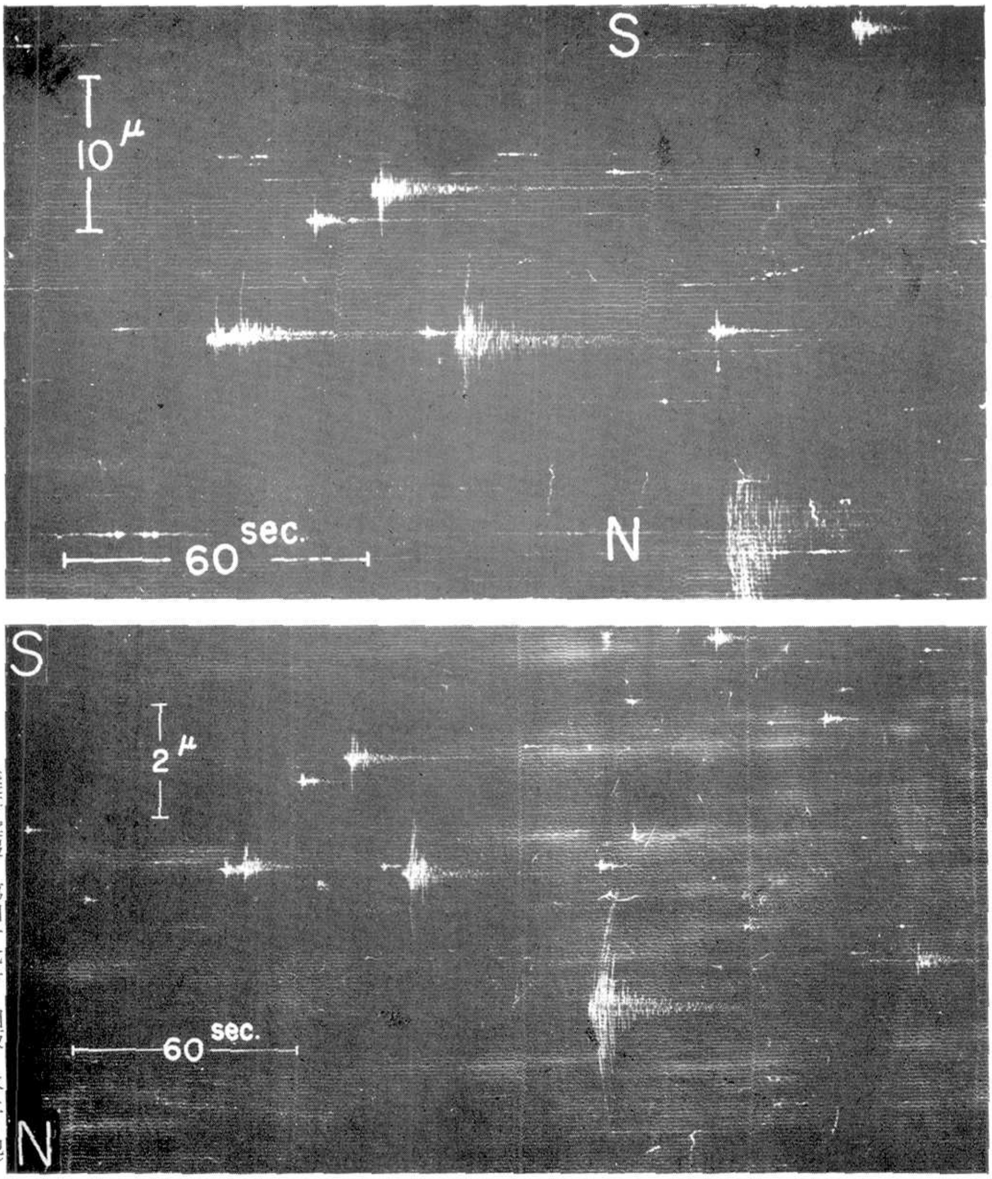

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Fig. 15. The seismogram of the earthquake on February 11, 1968, observed at two stations.